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Active

Project #: E-20-614 Cost share #: E-20-343 Rev #: 0
Center # : R6411-0A0 Center shr #: F6411-0A0 OCA file #: 90
Work type : RES
Contract#: BOA DTD 841109 TASK ORFER 9 Mod #: Document : TO
Prime #: Contract entity: GTRC

Subprojects ? : N
Main project #:

Project unit: CE Unit code: 02.010.116
Project director(s):
LAI J S CE

Sponsor/division names: GA DEPT OF TRANSPORTATION /
Sponsor/division codes: 300 / 035

Award period: 870513 to ~~871013~~ 2/18/88 (performance) 871013 (reports)

Sponsor amount	New this change	Total to date
Contract valu	9,662.00	9,662.00
Funded	9,662.00	9,662.00
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Does subcontracting plan apply ?: N

Title: EVALUATION OF THE EFFECT OF GRADATION ON ASPHALTIC CONCRETE MIXTURE PROPERTIES

PROJECT ADMINISTRATION DATA

OCA contact: Brian J. Lindberg 894-4820

Sponsor technical contact	Sponsor issuing office
PERCY B. MIDDLEBROOK, JR.	BRUCE E. CAMPBELL
(404)363-7567	(404)363-7583
GA DOT-OFFICE OF MATERIALS & RESEARC	GA DOT-OFFICE OF MATERIALS & RESEARC
15 KENNEDY DRIVE	15 KENNEDY DRIVE
FOREST PARK, GA 30050-2599	FOREST PARK, GA 30050-2599

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : N/A N/A supplemental sheet
Equipment title vests with: Sponsor X GIT
HOWEVER, NONE PROPOSED OR ANTICIPATED.

Administrative comments -
INITIATION OF PROJECT E-20-614.

GEORGIA INSTITUTE OF TECHNOLOGY   OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/16/88

Project No. E-20-614   School/~~Lab~~ CE

Includes Subproject No.(s) N/A

Project Director(s) J. S. Lai   GTRC/~~GIT~~

Sponsor Georgia Dept. of Transportation

Title Evaluation of the Effect of ~~Grdation~~ Gradation on Asphaltic Concrete Mixture Properties

Effective Completion Date: 2/18/88 (Performance) 2/18/88 (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [x] Final Invoice or Copy of Last Invoice Serving as Final
- [ ] Release and Assignment
- [ ] Final Report of Inventions and/or Subcontract:
  Patent and Subcontract Questionnaire sent to Project Director [ ]
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ______

Continues Project No. ______ Continued by Project No. ______

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E-20-614

Contract Research

GaDOT Research Project No. 8706

FINAL REPORT

EVALUATION OF THE EFFECT OF GRADATION OF AGGREGATE ON RUTTING CHARACTERISTICS OF ASPHALT MIXES

by

James S. Lai
Professor of Civil Engineering
School of Civil Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Prepared for

Georgia Department of Transportation
Office of Materials and Research

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Abstract

Segregation of asphalt mixes has become a serious problem on coarse base mixes when they are improperly handled during manufacturing, transporting and placement. One method of minimizing segregation is to increase the amount of fine portion of aggregates. However, this may potentially affect the properties of the asphalt mixes, particularly the rutting resistance.

The purpose of this study is to evaluate the effect of mix gradations on the rutting resistance of the asphalt mixes. Six mix gradations show below from three aggregate sources were selected in this study.

	Type	Max. Agg. Size	% Passing #8 Sieve
1.	Standard Type B Mix	1	38%
2.	Base Mix	1-1/2	35%
3.	Coarse B Mix	1	33%
4.	Modified X Mix	3/4	30%
5.	Modified XX Mix	3/4	38%
6.	Modified Base Mix	1-1/2	22%

Prediction of rutting potential was based on a laboratory procedure whereby the asphalt beam samples made in the laboratory were subjected to a repetitive wheel load to 8000 cycles. The rut-depth developed along the wheel path on the beam samples was measured and was used as the basis for evalauting the rutting potential of the mixes.

Results obtained from this study indicated that modified X mixes can substantially improve the rutting resistance while the modified XX mixes decrease the rutting resistance as compared with the Standard Type B mixes and the Base mixes. The modified base mix, because of insufficient fines, also decrease rutting resistance. This study also showed that aggregate sources can significantly affect the rutting potential of asphalt mixes.

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CHAPTER 1

INTRODUCTION

Segregation of asphaltic concrete paving mixtures has been an annoying problem on bituminous construction projects. These problems have become more noticeable since the advent of drum mix plants with large capacity storage silos. Other factors such as mechanical problems, placement procedures and coarse mixture gradations also affect the degree of segregation. While modifications of equipment and construction procedures has reduced the extent of the problem, segregation continues to exist.

In 1986, the Georgia Department of Transportation (GDOT) took an aggressive stand against segregation of asphalt mixtures. A policy was adopted that would discontinue work on projects where segregated mixtures were encountered. After the problem was investigated and steps were taken to correct the mix, a test section was placed to determine if the corrective action was adequate. While this policy has reduced segregation of mixtures, the problem continues to plague transportation officials and contractors throughout the state.

One method of eliminating segregated mix is to increase the amount of material finer than the largest nominal aggregate size particles normally used in a particular mixture. The fine aggregate portion of the mix is considered to be the amount finer than a No. 8 sieve. While this approach may minimize the segregation problem, changing the percentage of fine aggregate could affect the properties of the asphalt mixes produced. Among the asphalt mix properties which could be affected by the changing and which would have significant effect on the performance of asphalt pavements is the rutting resistance.

In the two previous studies conducted by Lai [1,2] for GaDOT, it has been demonstrated that the loaded wheel testing machine is capable of evaluating the rutting characteristics of asphalt concrete. In the study [2], the loaded wheel testing machine was used to assess the rutting potential of GaDOT Type B asphalt mixes and the six modified mixes using aggregates from three different sources. Although all twenty-one mixes met the Marshall mix criteria, they exhibited significantly different rutting characteristics when tested under the loaded wheel testing machine. From these test results certain modified mixes which have the potential to prove the rutting characteristics were identified.

This research project was initiated to evaluate the effect of varying the fine aggregate portion of asphalt mix gradations on the rutting resistance of the asphalt mixes. Because of the obvious advantages and the ability of the loaded wheel testing machine in assessing the rutting characteristics of asphalt concrete, the same testing procedures are used in this study to evaluate the rutting characteristics of the asphalt mixes. This report summarizes the results of this study.

CHAPTER 2

MATERIALS AND SAMPLE PREPARATION

The aggregates used for this study were from Vulcan Materials Company at the following three plants:

Dalton, Ga.	(D)
Kennsaw, Ga.	(K)
Lithia Springs, Ga.	(L)

Six gradations, including the standard gradations for the Type B binder course, for each aggregate source were prepared. The gradations are identified as follows:

	Type	Max. Agg. Size	% Passing No. 8 Sieve
1.	Standard Type B (B)	1	38%
2.	Base Mix (BA)	1-1/2	35%
3.	Coarse B Mix (CB)	1	33%
4.	Modified X Mix (X)	3/4	30%
5.	Modified XX Mix (XX)	3/4	38%
6.	Modified Base Mix (XBA)	1-1/2	22%

The gradations of these mixes are presented in Tables 1, 2 and 3 and also in Figure 1. All the mixes have 1% lime as a part of the filler.

Marshall mix design for the 16 mixes listed in Tables 1, 2 and 3 were performed at the GaDOT Materials Laboratory. Results of the Marshall mix design are summarized also in Tables 1, 2 and 3. The asphalt contents used for preparing the beam samples for each mix were based on the Marshall mix design results at about 4.5% air voids. The actual air voids in the corresponding Marshall mixes for the 16 mixes varied between 4.5% to 4.7%. The DXX mix was the only exception which had air voids of 4.3%.

The materials, aggregates and asphalt, needed to fabricate the 3"x3"x15" beam samples for this study were provided by GaDOT. Based on the

Table 1. Gradations and Asphalt Mix Characteristics

Aggregate Source: Dalton, Georgia

COMBINATION	BA	B	CB	X	XX
SOURCE	Vulcan @ Dalton	Vulcan @ Dalton	Vulcan @ Dalton	Vulcan @ Dalton	Vulcan @ Dalton
BLEND	28% - 5 16% - 7 40% - 012 15% - Min 1% - Lime	36% - 6 19% - 89 33% - Mio 11% - Min 1% - Lime	36% - 6 12% - 89 36% - 012 15% - Min 1% - Lime	40% - 7 30% - 89 12% - Mio 17% - Min 1% - Lime	40% - 7 19% - 89 20% - Mio 20% - Min 1% - Lime
GRADATION: 1½	100				
1	98	100	100		
3/4	82	98	98	100	100
1/2	73	77	77	97	97
3/8	64	68	67	80	80
4	43	52	44	41	48
8	34	38	33	30	38
16	28	27	25	24	30
30	22	19	20	20	24
50	13	12	12	11	13
100	8	7	6	6	7
200	5	5	5	4	5
DESIGN DATA: OPT. A.C.	4.5	4.7	4.8	5.2	5.1
THEO. GRAV.	2.629	2.568	2.604	2.577	2.602
ACTUAL GRAV.	2.508	4.452	2.487	2.460	2.490
% VOIDS	4.6	4.5	4.5	4.5	4.3
DENSITY	156.5	153.0	155.2	153.5	155.4
VMA	15.5	15.6	16.1	16.3	16.6
% VOIDS FILLED	70.3	71.1	71.5	72.4	74.1
STABILITY	2140	2130	1880	1810	2120
FLOW	11.6	10.0	10.7	12.2	11.0
EFF. GRAV.	2.835	2.770	2.820	2.806	2.832
T/S (% VOIDS)	6.2	5.7	7.0	6.6	6.3
T/S (CONTROL)	101.2	118.9	95.2	90.3	76.2
T/S (CONDITIONED)	85.3	97.6	76.8	72.1	77.7
% RETAINED	84.3	82.1	80.7	79.8	102.0
MODIFIED T/S	45.8	41.2	39.2	36.9	37.0
STIFFNESS	11,475	11,019	10,068	8,311	9,287
RUT DEPTH (8000 CYCLES)	.182	.229	.208	.218	.285

Table 2. Gradations and Asphalt Mix Characteristics

Aggregare Source: Kennesaw, Georgia

COMBINATION	BA	B	CB	X	XX
SOURCE	Vulcan @ Kennesaw	Vulcan @ Kennesaw	Vulcan @ Kennesaw	Vulcan @ Kennesaw	Vulcan @ Kennesaw
BLEND	30% - 5 17% - 7 30% - 810 22% - 777 1% - Lime	27% - 6 16% - 7 26% - 810 30% - 777 1% - Lime	23% - 6 28% - 7 30% - 810 18% - 777 1% - Lime	50% - 7 8% - 89 27% - 810 14% - 777 1% - Lime	45% - 7 29% - 810 25% - 777
GRADATION: 1½	100				
1	99	100	100		
3/4	84	99	100	100	100
1/2	71	81	83	97	97
3/8	62	67	66	80	80
4	48	54	46	43	53
8	35	38	33	30	38
16	26	27	24	21	27
30	20	21	19	16	20
50	14	14	13	12	14
100	9	8	8	8	9
200	5	5	5	5	5
DESIGN DATA: OPT. A.C.	4.8	5.0	4.9	5.3	5.3
THEO. GRAV.	2.579	2.576	2.569	2.561	2.559
ACTUAL GRAV.	2.458	2.457	2.452	2.444	2.441
% VOIDS	4.7	4.6	4.6	4.6	4.6
DENSITY	153.4	153.3	153.0	152.5	152.3
VMA	16.0	16.5	16.2	17.1	17.1
% VOIDS FILLED	70.6	72.1	71.6	73.1	73.1
STABILITY	3000	3170	2810	2880	3010
FLOW	10.2	12.1	11.0	11.6	11.8
EFF. GRAV.	2.789	2.795	2.782	2.791	2.789
T/S (% VOIDS)	6.2	7.1	6.9	7.1	7.3
T/S (CONTROL)	107.8	117.1	109.5	112.2	107.5
T/S (CONDITIONED)	88.9	86.0	89.2	80.2	85.2
% RETAINED	82.5	73.4	81.5	71.5	79.3
MODIFIED T/S	47.3	45.6	39.4	44.9	48.8
STIFFNESS	9002	17,902	10,835	10,147	12,349
RUT DEPTH (8000 CYCLES)	.184	.217	.208	.137	.169

Table 3. Gradations and Asphalt Mix Characteristics

Aggregate Source: Lithia Springs

COMBINATION	BA	B	CB	X	XX	LXBA
SOURCE	Vulcan @ Lithia Springs	Vulcan @ Lithia Springs	Vulcan @ Lithia Springs	Vulcan @ Lithia Springs	Vulcan @ Lithia Springs	Vulcan @ Lithia Springs
BLEND	28% - 5 17% - 7 45% - 810 9% - 777 1% - Lime	42% - 67 42% - 810 15% - 777 1% - Lime	50% - 67 40$ - 810 9% - 777 1% - Lime	38% - 7 17% - 89 38% - 810 6% - 777 1% - Lime	41% - 7 42% - 810 16% - 777 1% - Lime	36% - 5 32% - 7 20% - 810 11% - 777 1% - Lime
GRADATION: 1½	100					100
1	98	100	100			97
3/4	83	99	99	100	100	78
1/2	73	84	81	98	98	63
3/8	64	71	66	80	79	48
4	48	52	45	45	53	30
8	35	38	33	30	38	22
16	26	27	24	21	28	17
30	19	20	18	16	21	13
50	13	13	12	11	14	9
100	8	9	8	7	9	6
200	5	5	5	5	5	4
DESIGN DATA: OPT. A.C.	4.8	5.3	5.1	5.5	5.3	5.0
THEO. GRAV.	2.450	2.429	2.438	2.424	2.422	2.440
ACTUAL GRAV.	2.338	2.317	2.327	2.316	2.311	2.327
% VOIDS	4.6	4.6	4.6	4.5	4.6	4.6
DENSITY	145.9	144.6	145.2	144.5	144.2	145.2
VMA	15.4	16.5	16.0	16.8	16.4	15.9
% VOIDS FILLED	70.1	72.1	71.3	73.2	72.0	71.1
STABILITY	2970	2930	2740	2580	2710	2280
FLOW	10.8	10.4	12.0	10.0	9.6	13.2
EFF. GRAV.	2.631	2.627	2.629	2.630	2.618	2.628
T/S (% VOIDS)	6.3	6.0	6.7	7.0	6.7	5.7
T/S (CONTROL)	99.8	112.1	92.8	94.8	111.3	78.8
T/S (CONDITIONED)	88.7	98.2	91.1	80.7	101.5	66.3
% RETAINED	88.9	87.6	98.2	85.1	91.2	84.1
MODIFIED T/S	43.5	54.4	46.5	34.3	54.0	31.0
STIFFNESS	12,783	15,943	11,164	8,334	15,421	12,247
RUT DEPTH (8000 CYCLES)	.211	.198	.212	.162	.220	.210

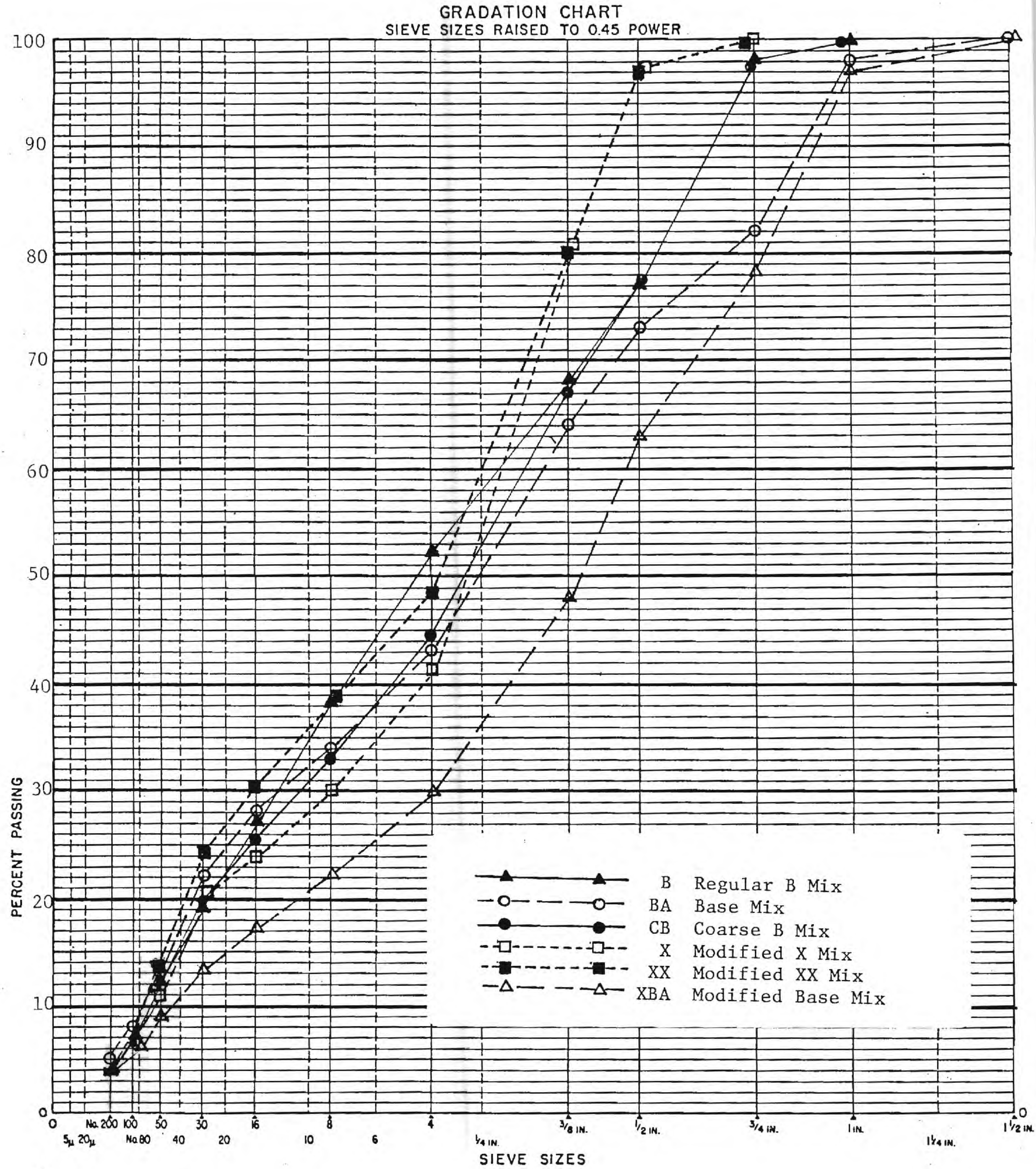

Figure 1. Gradation of Six Mixes

bulk density of each mix from the Marshall mix design, and the known volume of the beam mold, aggregate samples for 1/3 beam volume were batched for all the mixes. A total of 9 batches per mixes, three per each beam sample, were prepared at GaDOT Materials Laboratory. During the batching of the mixes, aggregates and the asphalt cement were heated separately at 360°F and 315°F respectively.

The following describes the beam sample preparation procedures. The heated aggregates from the oven were poured into a mixing bowl and a 1% hydrated lime (by wt. of aggregates) was added to the aggregate. The aggregate and the lime were dry mixed and the optimum amount of asphalt was introduced and then the materials were thoroughly mixed by hand. The heated beam mold was placed on a sliding rack in the kneading compactor and the asphalt mix spooned into the mold. The 3"x1" loading foot of the kneading compactor was activated to compress the mix in the mold. During the compaction of the mixes in the beam mold, the beam was manually moved length-wise so that the entire beam would be subjected to an equal amount of compaction effort. Relatively low pressure was used initially and as the mix became more stable pressure gradually increased until the mix in the mold was compressed to the predetermined height. At this point, the next batch of asphalt mix was prepared and spooned into the beam mold and the compaction resumed. After the third batch of asphalt mix was in the mold and was compressed to approximately the required height, a thick loading plate 3"x15" in size was placed on top of the beam and a high pressure was applied on it to compress the mix in the mold to the final required height, flush with the 3 in. high side mold. This ensured that the beam prepared was compacted to the same density as that from the Marshall samples. After the beam samples were allowed to cool overnight and were removed from the molds, the dimensions of each beam were measured and the bulk density was determined using the water displacement method. Results of the averaged bulk density of the beam samples and the air voids contents determined from the voidless mix density (given in Tables 1, 2 and 3) and the bulk density of the beam samples are presented in Tables 4,5 and 6. The differences in the air voids contents among mixes are substantial.

CHAPTER 3

RUT TEST PROCEDURES AND RESULTS

The modified loaded-wheel testing machine was described in [1]. There have been some minor modifications made on the machine to simplify the set-up and the data collection procedures.

The testing procedures used in this study were similar to that used in the previous studies [1,2]. The following were the test conditions used in this study:

Temperature	105°F
Load	100 lbs.
Contact Pressure	100 psi
Frequency	22 cycles/min.

During the test, rutting profiles of the beam samples along the wheel path were measured at 0, 200, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, and 8000 cycles. For each mix two tests were conducted first. If the results from these two tests were not consistent, then a third test was conducted. Results from each beam test and the averaged values for each mix are presented in Tables 4, 5 and 6. The test results that were not used are marked "omit" in Tables 4, 5 and 6. The decision to omit these test results were based on the obvious discrepancies in the test results and also based on the unusual failure exhibited on the test specimens. It needs to be pointed out that normally rut-depth values at three positions at the mid-portion of the beam along the wheel path were used and averaged to obtain the rut-depth value at the given load repetitions. In some tests, due to the presence of a large aggregate particle around these measuring points, or other causes, which resulted in particularly high or low reading at these locations. When this happened, the readings from this particular position were disregarded and the readings from the remaining two positions were averaged for the rut-depth values. These are noted in Tables 4, 5 and 6 by (#). Results of the averaged rut-depth value versus the number of repetitions for all the mixes are also shown in Figures 2, 3 and 4.

Table 4 Rutting Results of Different Modified Type B Mix

CODE DESCRIPTION:

BA= BASE
B= REGULAR B
CB= COARSE B
X= MODIFIED X
XX= MODIFIED XX

AGGREGATE SOURCES: Dalton, GA

Mix Type	Air Voids	Unit Weight	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles 200	500	1000	2000	3000	4000	5000	6000	7000	8000	Notes
	5.0%	152.2	56	74	97	124	148	166	182	194	209	215	
	5.0%	152.2	65	85	108	141	166	184	199	214	227	243	
	6.1%	150.5											
DB	5.4%	151.6	61	80	103	133	157	175	191	204	218	229	
	5.9%	154.3	73	91	108	129	146	157	167	172	182	189	
	6.1%	154.1	58	76	89	107	121	135	146	163	169	175	
	6.6%	153.3											
DBA	6.2%		66	84	99	118	134	146	157	168	176	182	
	5.2%	154.0	79	105	123	149	167	181	191	196			
	5.2%	154.0	85	105	125	154	173	185	198	209	216		
	5.3%	153.8	65	81	136	146	159	176	192	230	232	223	omit
DCB	5.3%		82	105	124	152	170	183	195	203	216		
	6.3%	150.6	80	99	117	141	159	178	190	195		212	
	5.1%	152.6	72	94	115	135	152	174	189	203	213	223	
	5.9%	151.3											
DX	5.8%		76	97	116	138	156	176	190	199	213	218	
	3.8%	156.2	64	81	106	142	194	215	239	253	274	294	
	3.7%	156.3	57	76	107	151	178	200	226	246	261	275	
	3.9%	156.0											
DXX	3.8%	156.2	61	79	107	147	186	208	233	250	268	294	

Table 5 Rutting Results of Different Modified Type B Mix

CODE DESCRIPTION:

BA= BASE
B= REGULAR B
CB= COARSE B
X= MODIFIED X
XX= MODIFIED XX

AGGREGATES SOURCES: Kennesaw, GA

Mix Type	Air Viods	Unit Weight	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles 200	500	1000	2000	3000	4000	5000	6000	7000	8000	Notes
	5.7%	151.5	46	66	98	136	158	177	194	204	210	219	
	5.1%	152.5	41	60	87	125	153	173	187	197	206	214	
	5.9%	151.3	40	56	84	119	145	160	171	179	187	191	
KB	5.6%		42	61	90	127	152	170	184	193	201	208	
	5.9%	151.5	47	57	75	88	100	115	130	144	154	164	#
	7.4%	149.0	42	60	74	95	117	132	145	154	165	174	
	7.5%	148.9	49	71	90	118	148	165	183	197	206	215	
KBA	6.9%		46	63	80	100	122	137	153	165	175	184	
	5.6%	151.3	79	99	124	153	169	185	193	205	214	223	omit
	5.3%	151.8	64	82	100	136	150	164	173	182	187	193	
	6.1%	150.5											
KCB	5.7%	151.2	64	82	100	136	150	164	173	182	187	193	
	5.9%	150.4	53	65	75	95	102	106	116	123	126	143	#
	5.5%	151.0	28	38	57	79	86	91	113	124	138	155	
	6.2%	149.9	54	71	86	116	129	141	165	172	186	192	
KX	5.9%		45	58	73	97	106	113	131	140	150	163	
	6.5%	149.3	58	78	94	124	133	143	154	174	195	207	#
	6.8%	148.8	50	61	80	105	119	130	136	146	151	156	omit
	6.9%	148.6	58	78	103	132	153	206	187	203	216	226	
KXX	6.8%		58	78	99	128	143	175	171	189	206	217	

Table 6 Rutting Results of Different Modified Type B Mix

CODE DESCRIPTION:

BA= BASE
B= REGULAR B
CB= COARSE B
X= MODIFIED X
XX= MODIFIED XX

AGGREGATE SOURCES: Lithia Springs, GA

LXBA= MODIFIED BASE MIX

Mix	Air	Unit	BEAM RUT-DEPTH ,1/1000 IN. @ #Cycles										Notes
Type	Voids	Weight	200	500	1000	2000	3000	4000	5000	6000	7000	8000	
	7.0%	141	58	72	90	118	130	140	153	159	171	182	#
	5.9%	142.6	52	65	83	108	127	144	158	170	176	185	
	5.1%	143.9											
LB	6.0%		55	69	87	113	129	142	156	165	174	184	
	5.5%	144.4	62	77	107	124	150	167	176	200	204	211	
	6.8%	142.5	14	37	63	97	125	147	171	182	195	211	
	6.4%	143.1	68	89	115	152	184	195	204	213	224	233	#
LBA	6.2%		48	68	95	124	153	170	184	198	208	218	
	6.4%	142.4	64	80	109	141	167	178	189	197	200	203	#
	6.6%	142.1	66	96	113	138	156	172	184	199	215	226	
	7.3%	141.0	54	68	111	137	153	168	180	190	198	204	#
LCB	6.8%		61	81	111	139	159	173	184	195	204	211	
	5.5%	142.9	62	86	101	122	135	143	154	161	165	171	
	5.1%	143.5	47	60	70	96	111	122	130	140	146	153	
	5.0%	143.7											
LX	5.2%		55	73	86	109	123	133	142	151	156	162	
	4.6%	144.2	62	85	113	140	150	173	186	197	206	214	
	5.4%	142.9	93	124	149	184	207	225	239	251	278	273	omit
	4.7%	144.1	51	71	102	134	164	181	194	206	217	226	
LXX	4.9%	143.7	57	78	108	137	157	177	190	202	212	220	
		147.6	115	139	172	185	196	205	211	222	239	245	
		147.4	54	72	86	114	139	154	194	201	203	210	
		147.2	75	105	130	176	199	214	228	239	243	247	
LXBA		147.4											
			81	105	129	158	178	191	211	221	228	234	

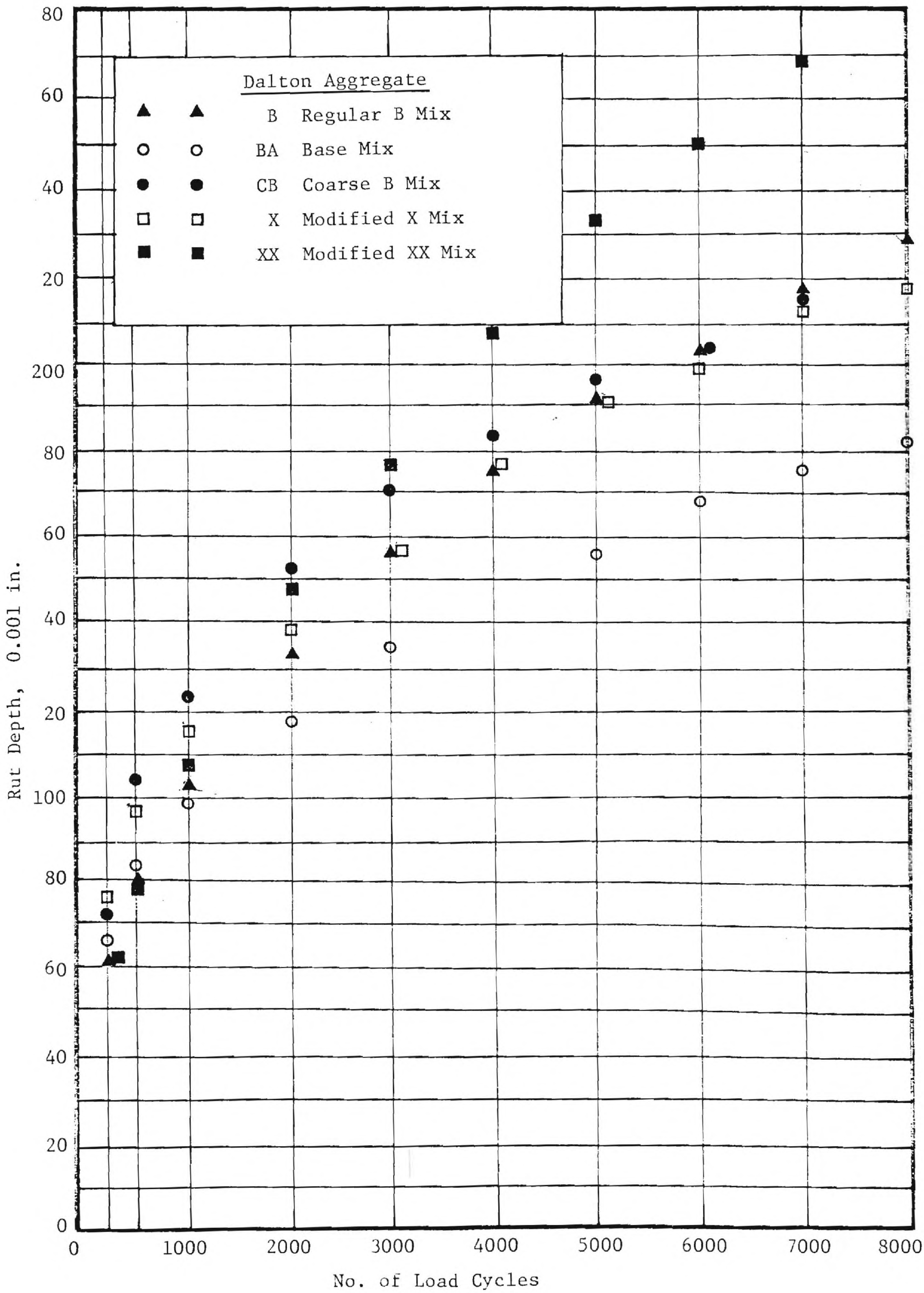

Figure 2. Rut-Depth vs No. of Load Repetitions

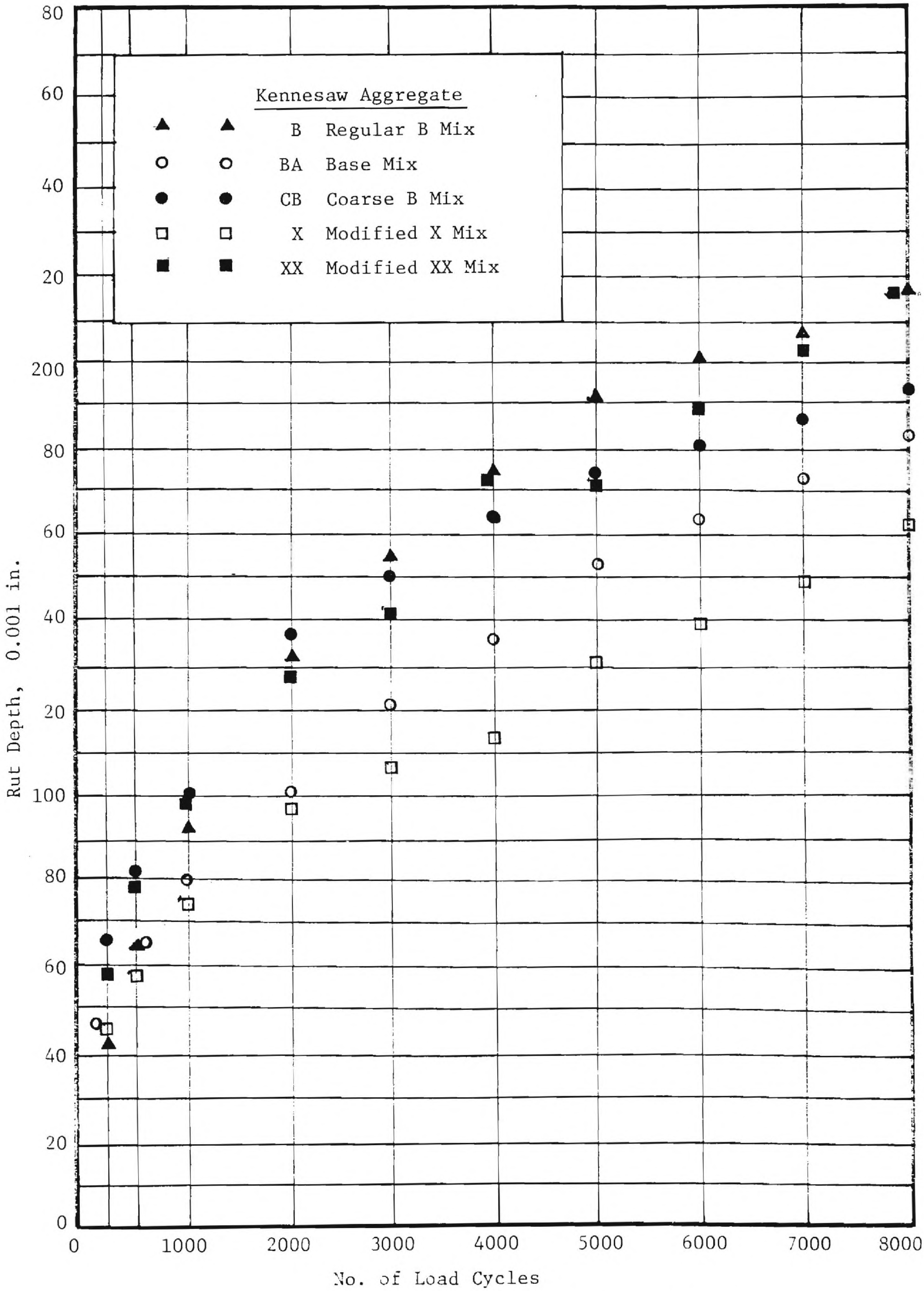

Figure 3. Rut-Depth vs No. of Load Repetitions

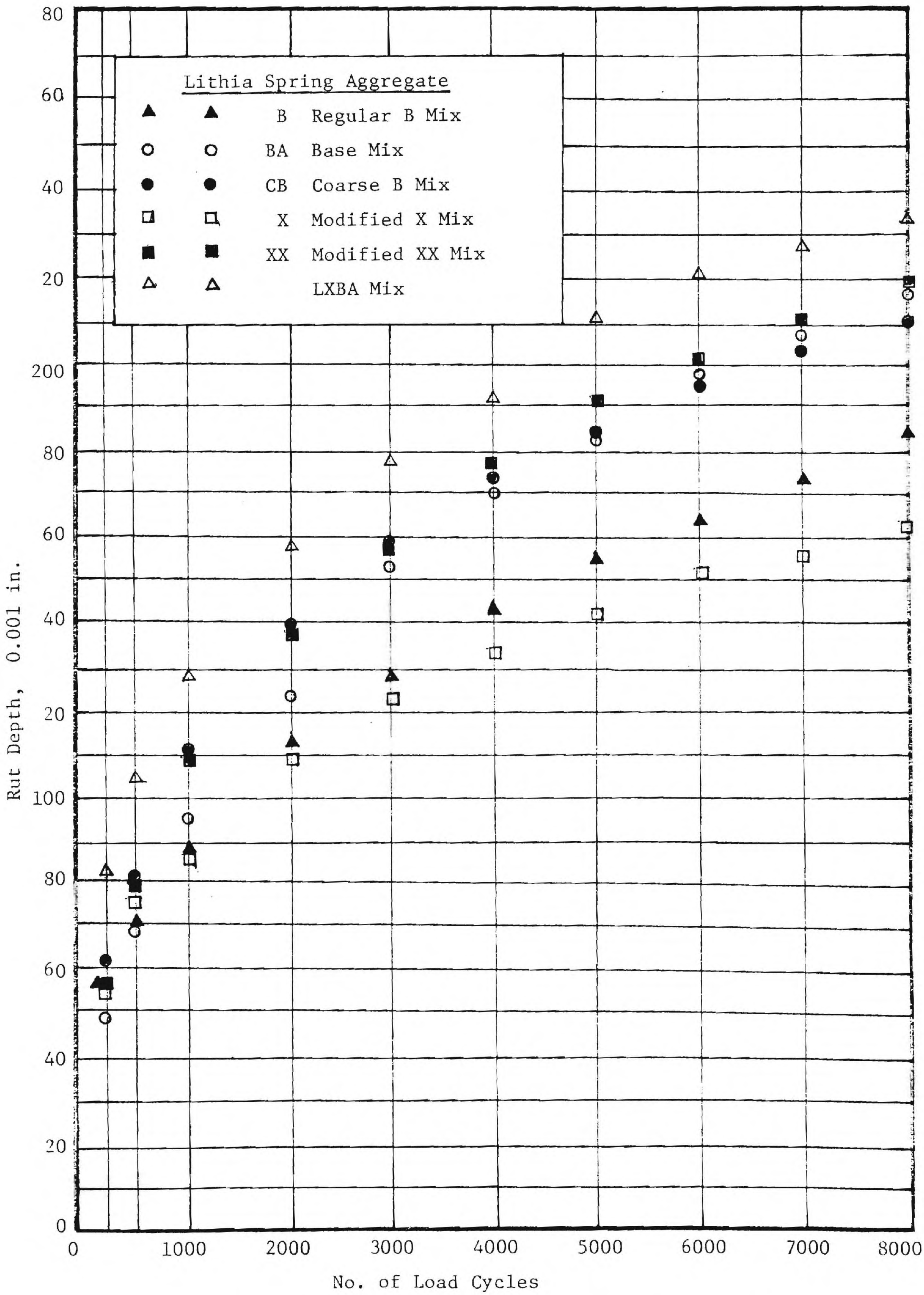

Figure 4. Rut-Depth vs No. of Load Repetitions

CHAPTER 4

ANALYSIS AND DISCUSSION

The rutting curves for different mixes shown in Figures 2,3 and 4 displayed divergence with increase in the number of repetitions and there were very little cross-over among different rutting curves, particularly from N=4000 and beyond. Therefore in most of the following analyses and discussions, rut-depth values taken at N=8000 cycles were used to represent the rutting characteristics of the mixes.

Comparison of Different Aggregate Sources

The purpose of this analysis was to determine if aggregates from different sources may affect the rutting characteristics of asphalt mixes. The magnitudes of rut-depth at N=8000 for the 16 mixes were arranged in descending order as shown in Table 7. Some trends could be seen from this ranking, particularly those mixes using the aggregate from Dalton seem to have higher rut-depth than that from the two other aggregate sources. To quantify that, rut-depth values at N=8000 for the five mixes, excluding LXBA mix, from the three aggregate sources were separately averaged. The average values shown in Table 7 showed a significant difference, with the mixes using aggregates from Dalton showing a significantly higher rutting than that from the mixes using the other two aggregates. There was not significant difference of the averaged rutting between those mixes using aggregates from Kennesaw and from Lithia Springs.

The aggregate from Dalton is limestone and the particles of the coarse aggregates tend to be more elongated and flaky while the aggregates from Kennesaw and Lithia Springs are granite and the particles tend to be more

Table 7. Summary of Rut-Depth of Different Mixes

N = 8000 cycles

Mix Type	Rut-Depth (0.001")	Marshall Stability
DXX	294	2120
LXBA	234	
DB	229	1880
LXX	220	2710
DCB	220	1810
DX	218	2130
LBA	218	2970
KXX	217	3010
LCB	211	2740
KB	208	3170
KCB	193	2810
LB	184	2930
KBA	184	300
DBA	182	2140
KX	163	2880
LX	162	2580

Averaged Values

Dalton Agg (D)	229	2016
Kennesaw Agg ,K	199	2786
Lithia Springs (L)	193	2974
XX	244	2699
CB	208	2453
B	207	2660
BA	195	2703
X	181	2530

cubical and the surface textures rougher than the limestone from Dalton. The asphalt contents for the mixes using Dalton aggregate are lower than that from the other two aggregate sources. Averaging the asphalt contents from the five mixes (see Tables 1,2 and 3) yield 4.86%, 5.06% and 5.20% for Dalton, Kennesaw and Lithia Springs aggregates. This may reflect the differences in the absorption and the surface textures of the limestone from Dalton and the granite from the other two aggregate sources. The gradations are also slightly different. The averaged value of passing #50 and #100 for the three aggregate types are shown in Table 8. In the previous study [2], a comparison of the standard Type B binder course mixes with the the mixes using modified gradations where the percent passing #50 sieve was increased by about 3% showed that the modified mixes improved the rutting resistance by about 10% to 20% ranges. In that study, the percent passing #100 sieve was kept about the same. The gradations shown in Table 8 indicated that the difference in the gradation was in the percent passing #100 sieve. The difference of about 1.5% passing #100 sieve could be a contributing factor in affecting the rutting resistance. Another factor which could not be quantified is the particle size, or the surface areas of fines passing #200 sieve of these three different aggregate types. In the previous study [2], it was pointed out that this characteristic could be an important factor in affecting the rutting characteristic of asphalt mixes.

Comparison of Modified X and Modified XX Mixes

As shown in Tables 1, 2 and 3, both the modified X and modified XX mixes have 3/4 in. maximum aggregate size which is smaller than the top aggregate size of the other three types of mixes; B, BA and CB. The differences between the X mixes and the XX mixes are the percent of fines in the mixes. The X mixes have 30% passing #8 sieve; while the XX mixes have

Table 8. Averager Properties of Asphalt Mixes From Three Aggregate Sources

	Dalton	Kennesaw	Lithia Springs
Rut-Depth @ N = 8000 (0.001")	229	193	199
% passing			
#50 sieve	12.2	13.4	12.6
#100 sieve	6.8	8.4	8.2
Asphalt Content	4.86	5.06	5.2
Marshall Stability, lbs	2016	2974	2786
Marshall Flow	11.1	11.3	10.6

38% passing #8 sieve. Aside from the modified Base Mix (XBA) which has 22% passing #8 sieve, 30% and 38% passing #8 sieve represent the extremes of the fines among the five different types of mixes investigated. The effect of the amount of fines between X and XX mixes are very significant. The following summarizes the results of the rut depth measured at N=8000 cycles for these two types of mixes among the three aggregate sources.

These results clearly indicate that an increase of fines (passing #8 sieve) from 30% to 38% for the mixes containing 3/4 in. top size aggregate would significantly increase the rutting tendency among all mixes.

In the previous study [2], the effects of different fillers on the rutting resistance of asphalt mixes using the same loaded wheel testing method were investigated. The results shown in that study tend to support a general conclusion that higher percent of fines passing #50 sieve and #100 sieve would be beneficial in improving rutting resistance. More specifically, the adequate levels of percent passing #50 sieve and #100 sieve should be 11% to 12% and 7% to 8%, respectively. In that study [2], for the asphalt mixes using the aggregates from Fairmount, Ga., the gradations and the rutting results for the different mixes summarized in Table 10 substantiates those effects. For the FS, F3M and F5T mixes, the percent passing #50 sieve and #100 sieve were lower than the adequate levels, and the corresponding rut-depth values were higher than the other two mixes F3M and FHM. For the mixes using the other two aggregate sources, Dalton and Chattanooga, the percent passing of #50 sieve and #100 sieve for all the modified mixes were closer and the difference in the rutting among these mixes were less.

In this study, the results between X mixes and XX mixes tend to indicate that the percent passing #50 sieve and #100 sieve exceeding the

Table 9. Comparision of X Mix And XX Mix Properties

	Mix X	Mix XX	Difference
Top Agg Size	3/4	3/4	
% passing #8	3Ø%	38%	
Rut-Depth @ N = 8ØØØ (Ø.ØØ1 in.)			
D	218	29Ø	76
K	163	217	54
L	162	22Ø	58
AC Content			
D	5.2	5.1	
K	5.3	5.3	
L	5.5	5.3	
Stability, lbs			
D	181Ø	212Ø	
K	228Ø	3Ø1Ø	
L	258Ø	271Ø	
Flow, Ø.Ø1 in.			
D	12.2	11	
K	11	11.8	
L	1Ø	9.6	

Table 10. Effects of the Gradation of Fines on Rutting Resistance [2]

Aggregate Source: Fairmount, GA

	FS	F3M	F5M	F5T	FHM
% Passing					
#50 sieve	7%	9%	11%	8%	11%
#100 sieve	5%	6%	7%	5%	7%
Rut-Depth @ N = 2000 (0.001 in.)	88	92	71	103	63

adequate levels of 11% to 12% and 7% to 8% respectively may increase the rutting tendency. When one analyzes the Marshall stability and flow values of the mixes, as summarized in Table 9, one sees a rather different picture. The stability values of the XX mixes are consistently higher than that of the X mixes. There is not significant difference of the flow values among these mixes. The different responses of the loaded wheel rutting test results and the Marshall stability results point toward the basic difference of these two types of testing methods and the advantages of using the loaded-wheel testing method to assess the rutting potential of asphalt mixes.

Comparison of the Base Mix (BA) and the Modified Base Mix (XBA)

It has been known that too much fines in an asphalt mix can reduce its rutting resistance. This has been demonstrated by the results shown in the previous section. It is possible that insufficient fines in an asphalt mix could also lower the rutting resistance. To get a feel of how much of the effect of lowering the percent of fines on the rutting resistance of the mixes, a Modified Base Mix using the aggregate from Lithia Springs (LXBA) was devised. This modified base mix contained 22% fines as opposed to 33% fines for a typical base mix. Results summarized in Table 11 indicate that LXBA mix has a slightly higher rutting than that of the LBA mix. The higher rutting could also be due to low percent passing #50 sieve and #100 sieve. On the other hand, the Marshall test results showed that LBA mix has higher stability value and lower flow value than the corresponding properties for LXBA mix. The asphalt contents are 4.8% and 5.0% respectively for LBA and LXBA mixes. The higher asphalt content could contribute to the lower stability and higher flow values. The fact that rutting was not significantly higher for LXBA than LBA could be attributable to the 1-1/2

Table 11. Comparision of LBA Mix And LXBA Mix

	Mix LBA	Mix LXBA
Top Agg Size	1-1/2	1-1/2
% passing #8	33%	22%
#50	13%	9%
#100	8%	6%
Rut-Depth @ N = 8000 (0.001 in.)	218	234
AC Content	4.8	5
Stability, lbs	2970	2280
Flow, 0.01 in.	10.8	13.2
Air Voids, %	4.6%	4.6%

in. maximum aggregate used for these two mixes against the 3 in. wide beam samples which were rigidly confined during the test. The large aggregate particles tend to create point-to-point contacts between the aggregates and the rigid side walls and the base which would impede the deformation of the mixes under the repeated moving loads. If larger beam samples were used, the test results from LXBA mixes could exhibit a significantly greater rutting than that of the LBA mix.

Comparison of Standard B Mix (B) and Coarse B Mix (CB)

Both types of mixes have 1 in. top size aggregate with the B mixes content 38% fines and CB mixes content 33% fines. Table 12 summarizes the results of the rutting tests and the Marshall tests. The results of the rut-depth show no consistent trends among the mixes from the three different aggregate sources. In view of the errors in the sample preparations and testing, the differences in the rut-depth values shown in Table 12 are insignificant. This seems to imply that the 5% difference in the percent passing #8 sieve between these two types of mixes did not significantly change the rutting characteristics of the asphalt mixes. Results from the Marshall tests show that the B mixes have slightly higher stability values than the CB mixes.

Comparison of Standard B Mix (B) and Modified XX Mix (XX)

The difference between these two types of mixes is the top aggregate size which are 1 in. and 3/4 in. respectively for the B mixes and the XX mixes. Both types of mixes contain 38% fines. The results summarized in Table 13 show that the XX mixes have greater rutting than that of the corresponding B mixes. The difference in rut-depth between B mix and XX mix using aggregates from different sources varies significantly with the mixes

Table 12. Comparision of B Mix And CB Mix Properties

	Mix B	Mix CB	Difference (B - CB)
Top Agg Size	1	1	
% passing #8	38%	33%	
Rut-Depth @ N = 8000 (0.001 in.)			
D	229	220	9
K	184	211	-27
L	208	193	15
AC Content			
D	4.7	4.8	
K	5	4.9	
L	5.3	5.1	
Stability, lbs			
D	2130	1880	250
K	3170	2810	360
L	2930	2740	190
Flow, 0.01 in.			
D	10	10.7	-0.7
K	12.1	11	1.1
L	10.4	12	-1.6

using Dalton aggregates exhibiting most significant effect, the mixes using Kennesaw aggregates exhibit no significant effect and the mixes using aggregates from Lithia Springs exhibit some effect.

Table 13. Comparision of B Mix And XX Mix Properties

	Mix B	Mix XX	Difference (XX - B)
Top Agg Size	1	3/4	
% passing #8	38%	38%	
Rut-Depth @ N = 8000 (0.001 in.)			
D	229	294	65
K	184	217	9
L	208	220	36
AC Content			
D	4.7	5.1	
K	5	5.3	
L	5.3	5.3	
Stability, lbs			
D	2130	2120	10
K	3170	3010	160
L	2930	2710	220
Flow, 0.01 in.			
D	10	11	1
K	12.1	11.8	-0.3
L	10.4	9.6	-0.8

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The rutting potential based on the rut-depth values generated from the loaded wheel tester on the asphalt concrete beam samples was investigated. Sixteen asphalt mixes were evaluated which consist of six different mix gradations and three aggregate sources. The following are the conclusions and the recommendations based on the results obtained in the course of this study.

CONCLUSIONS

1. Asphalt mixes using aggregates from Dalton, Ga. exhibited a significantly higher rutting than that from the other two aggregate sources. The aggregate from Dalton is limestone and the particles are more elongated and flaky and the surfaces are smoother and less absorptive; the aggregates from Kennesaw and Lithia Springs are all granite and the particles are more cubical and the surfaces are rougher and have relatively higher absoprtion. Also, the percent passing #100 sieve was about 1.5% lower for the aggregates from Dalton than that from the other two aggregate sources. All these may have contributed to the difference in the rutting resistance.
2. The modified X and XX mixes, both having 3/4 in. top size aggregate and having respectively 30% and 38% fine portion of aggregate exhibited significantly different

rutting resistance. The modified X mixes exhibited the best rutting resistance (low rut-depth) while the modified XX mixes exhibited the worse among all the five mix gradations (excluding the modified base mix) tested. This would indicate that for the finer mixes too much of fine portion of aggregate could increase rutting. The results also indicate that the finer mixes, when properly controlling the fine portion of the aggregate, such as the modified X mixes used in this study, could be as stable and have very good rutting resistance as that of the base mixes.

3. The modified base mix (LXBA) which had 22% fine portion of aggregate exhibited higher rutting tendency than the standard base mix.

4. Results from the standard B mix, Base mix and Coarse B mix are inconclusive. The rutting resistance of these three types of mixes based on the test results are about the same, and the results fell in between those of the modified X mixes and the modified XX mixes.

RECOMMENDATIONS

1. Based on the results obtained in this study and the previous study [2], the rutting resistance and other mix properties of B mixes which contain less than 33% fine portion of aggregate should be evaluated. A lower percent of fines for this mix may improve further the rutting resistance. Although the effects of lowering the percent of fines on the other mix properties including segregation during construction should also be evaluated.

2. The possibility of using the modified X mixes as a substitution to the B mixes in flexible pavement construction deserves a further consideration. This type of mix has exhibited good rutting resistance, and would be easier to compact and has less tendency to segregate. The cost impact of using this type of mix should be evaluated.

3. Use of the loaded wheel testing method for evaluating rutting of asphalt mixes containing 1-1/2 in. top size of aggregate, such as the Base mix and the Modified Base Mix used in this study, should be further evaluated. The main concern is that the large aggregates used in the mixes and the relatively small test sample yield unacceptable test errors.

References

1. Lai, J.S., "Development of a Simplified Test Method to Predict Rutting Characteristics of Asphalt Mixes", GaDOT Research Project No. 8503, Final Report, Georgia Department of Transportation, July, 1986.

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